Application of GIS in Understanding and Communicating Interaction between Environmental Parameters and Sewer Blockages

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Abstract
Sewer main chokes (blockages) are a key performance indicator for Australian water utilities. Blockages caused by tree roots often result in wastewater overflow posing an environmental and health risk and also requiring service interruptions to repair asset. The purpose of the research project outlined in this paper was to understand the role of environmental parameters, in particular soil type and tree density, in determining the propensity of a sewer to become blocked. The paper demonstrates the application of spatial analysis to inform and communicate the results of the analysis. GIS was used to explore the relationship between tree density and previously recorded sewer blockages for a Melbourne utility. Initial results from the research reveal a relationship between increased tree densities and occurrence of sewer blockages. An improved understanding of the influence of environmental parameters on the inherent risk of sewer blockage will enable asset managers to identify those assets requiring proactive management in order to minimise service interruptions, repairs and environmental impacts.

Introduction
Sewer blockages are a significant problem for Australian water utilities contributing substantially to the annual maintenance and repair expenditure for wastewater assets, which in 2002/03 totalled approximately $82 million (Water Services Association of Australia (WSAA), 2003). In the 2005/06 reporting period urban water utilities servicing capital cities reported an average sewer main breaks and choke[1] rate of 7.56 per 1000 properties, with 69% of chokes caused by tree roots (WSAA, 2007). Blockages caused by tree roots result in wastewater overflow posing an environmental and health risk and also requiring service interruptions to repair the asset. Despite the impact of sewer blockages caused by tree roots there is a paucity of information available to water utilities on how best to identify and proactively manage those sewers that are more likely to experience a blockage. This is due in part to the occurrence of a sewer blockage being the result of the complex interactions between material characteristics of the sewer pipe, soil moisture levels and tree roots.

This paper provides an overview of the GIS analysis that was undertaken as part of a project that is trying to determine the interdependence of environmental parameters and sewer blockages. The analysis focused on sewer mains with diameters ranging from 100mm to 300mm. GIS and spatial analysis has been used primarily for two purposes in this project. Firstly, to derive the data necessary to start exploring the relationship between an individual sewer and the local environment. The data derived from spatial analysis was then used in a regression analysis to determine the relationship between environmental parameters and the incidence of sewer blockages. Secondly, GIS was used to provide a visual representation of results that could be used to communicate the interaction between environmental parameters and both recorded and predicted sewer blockages.

Materials and Methods
The GIS analysis was carried out using ESRI ArcMap 9.2 (ArcInfo) software. The following sections describe the data sources for the project and the spatial analysis methods used to analyse the data

Study Site
This project was undertaken on a Melbourne water utility sewer network. The total length of sewer mains in the network is almost 8,000 kilometres, and in the reporting period 2006/07 the utility reported 21 sewer breaks and chokes per 100 kilometres of sewer mains with 75% of these caused by tree roots (WSAA, 2008). For sewer property connections the rate of breaks and chokes is 7.2 for every 1,000 properties with 74% of these associated with tree roots.

Description of Data Sources
The water utility provided a database and associated GIS file of their total sewer pipe network and also a database of recorded blockages. They also provided a GIS layer of soil types for their network area. This soil layer classified and attributed with data from Grant (1972) who classified Melbourne soils for engineering purposes. Grant used the following parameters to define and classify terrain and soil units:

- Geological age of parent material
- Terrain pattern in terms of amplitude of local relief and mean drainage density

[1] WSAA (2007) defines a sewer choke as "partial or total blockage that may or may not result in a spill to the external environment from the sewer system". While a break is defined as "a failure of the sewer main which results in an interruption to the sewerage service" (WSAA, 2007).

- Topography
- Dominant soils
- Dominant vegetation

Tree data for the whole sewer network was difficult to obtain. The only readily available data available was from local councils who maintain GIS databases of trees on public land. GIS data on public trees was obtained from 5 local governments within the water utility area, which contained records of more than 250,000 trees. In many cases sewer mains are aligned with public easements, but they also can be laid on private land or in proximity to private land so that trees there can potentially interfere with sewers on public land. Therefore, the reliance of public tree databases was a limitation of the study.

Assigning Soil Types
There was a need to assign a soil type to each sewer asset. A GIS Intersect query was run to determine for each sewer pipe which soil type it occurred in. In cases where the pipe was situated across two soil types the sewer was assigned to the soil type in which the majority of the asset length occurred. The soil characteristic seen as most important in influencing the propensity for sewer blockages was soil strength or hardness as this has been found to impact on the potential spread of tree roots (Watt *et al*., 2003; Wang and Smith, 2004). Soil strength is influenced by texture and moisture content. Soil strength is spatially heterogeneous and is not often captured in broad-scale soil mapping projects. Therefore, it was decided to use soil texture, which is a commonly available attribute, as a surrogate for soil strength. It is difficult to determine the relative impact of different soil textures on root penetration potential due to the complexity of many interacting factors such as soil moisture, temperature, oxygen, soil nutrients, microbiology etc. While it is difficult to say how much better or worse one soil texture is when compared to another, in terms of potential root spread and vigour, the literature does show that tree root branching is more extensive in sandy soils when compared to clay for the same tree species (Gilman, 1990). For this project soil resistance to root growth was classified into nine categories that ranged from 0 for rock outcrops (most resistant) to 9 for sandy loams (least resistant).

Determining Tree Influence
Initially it was planned to base the analysis of the relationship between sewer blockages and trees on the basis of species. This was in part due to a unpublished research project that analysed blockage history for a Melbourne water utility and found eucalyptus and melaleuca were the two species most likely to be associated with sewer blockages (pers. comm. 2006). However, the propensity for these species to be associated with blockages is more likely to be due to their widespread occurrence. Therefore, this analysis focused on the presence or absence of trees within the vicinity of a sewer and any history of blockages in that sewer.

Although soil type and site conditions affect the lateral spread of roots, the modern tree-root concept confirms that most tree roots grow laterally in the top 1 m of soil and have a spread under unrestrictive soil condition about three time the diameter of the crown (Jim, 2003). Kozlowski, 1971, suggests that root length has been known to differ from 3 times, 2 times and one and a half times crown diameter in sand, loam and clay soil respectively, but generally the lateral spread is not less than 2 times the diameter of the tree crown.

In order to determine for each sewer the tree or trees in the vicinity whose root systems could penetrate the pipe it was necessary to approximate the spread of the root system. There has been a number of studies that have demonstrated a relationship between tree morphology, which was a recorded attribute in some council GIS street tree databases, and lateral root spread. Consultation with a horticultural expert, confirmed there is strong empirical evidence for correlation between diameter of tree canopy spread and lateral distribution of roots, with 2.5 to 3 times the canopy spread generally being accepted as a reasonable measure to estimate root spread. However, tree data collected from different local councils varied in the attributes collected and the completeness of the data, and canopy spread was not often recorded. There was however a complete record of all tree heights in the GIS shapefile. Sudmeyer *et al*. (2004) show for two tree families commonly grown as street trees (*Eucalyptus* and *Pinus*) that there is a strong correlation between tree height and lateral root spread, with root spread approximately 1.5 to 2.5 times tree height. To calculate the tree root 'zone of influence" a buffer was calculated for each tree that was 1.5 times the tree height. An intersect query with the buffer was then run to determine for each sewer asset the number (if any) of tree root zones that could potentially interfere with the sewer. This data was supplied to the statistical analysis as a tree density that is; the number of trees per lineal metre of pipe (whose tree roots could potentially reach the pipe).

Results and Discussion
The failure rate is calculated from the following:

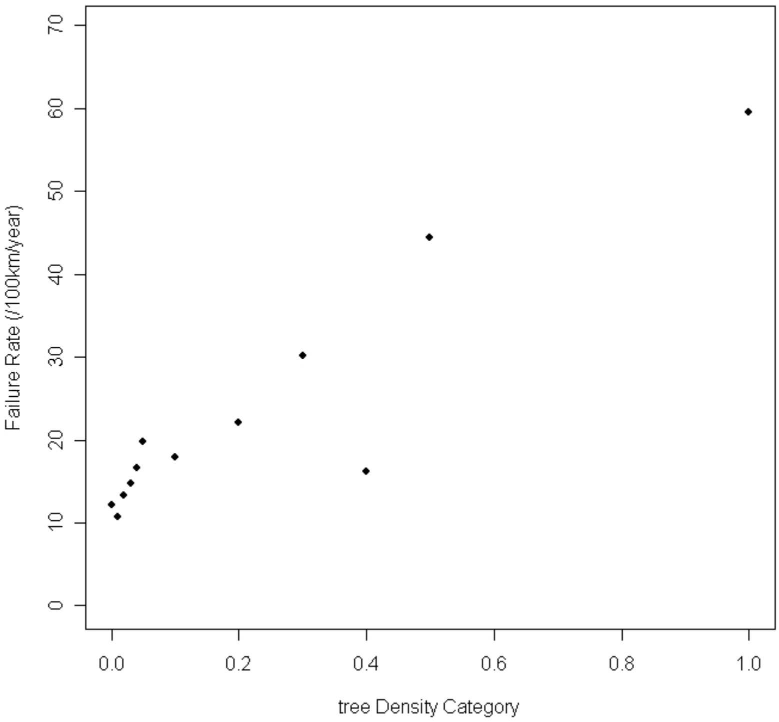
- The number of events for each sewer asset, which is the blockages recorded over the monitoring period 1996 to 2004, and
- the exposure, which is the product of the length of the pipe (in km) and the number of years the pipe was in the ground during the monitoring period (1996-2004).

The failure rate is the ratio of the above. Failure rate is expressed in the following unit: Number of blockages per 100 kilometre of pipe per year (averaged over the monitoring period).

The regression analysis is still under way to try and understand the relationship between certain environmental characteristics, such soil type and tree density, and the propensity of a sewer to block. Initial results have revealed the following:

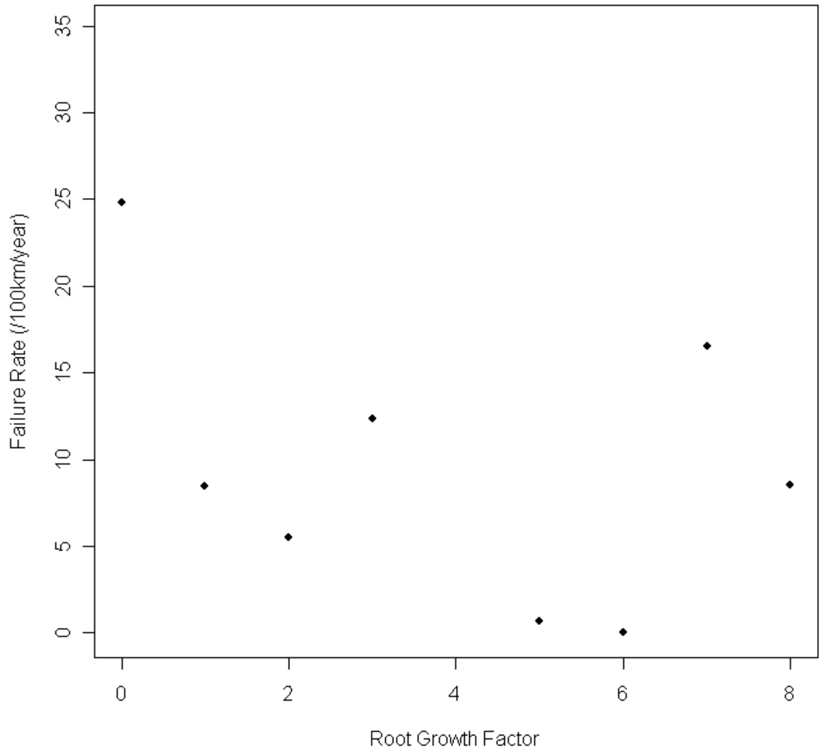
- That the failure rate increases in an almost linear fashion with tree density (See: Figure 1). Sewers that had more than 1 tree per lineal metre were uncommon and therefore results are not statistically reliable.
- The analysis at this stage has not found a clear relationship between soils impendence to root growth and propensity for blockage. Figure 2 shows that no relationship is clearly defined between decreasing root growth impedance (9 is sand loam) and increased blockages. The anomalously high failure rate recorded for Root Growth Factor 0 (rock outcrop) may have been influenced by the very limited amount of pipe occurring in this category.

Figure 1: Failure rate versus tree density – 1996 2004



Tree Density: Number of tree root zones per lineal metre of pipe

Figure 2: Failure rate versus Soil Root Growth Factor– 1996 2004



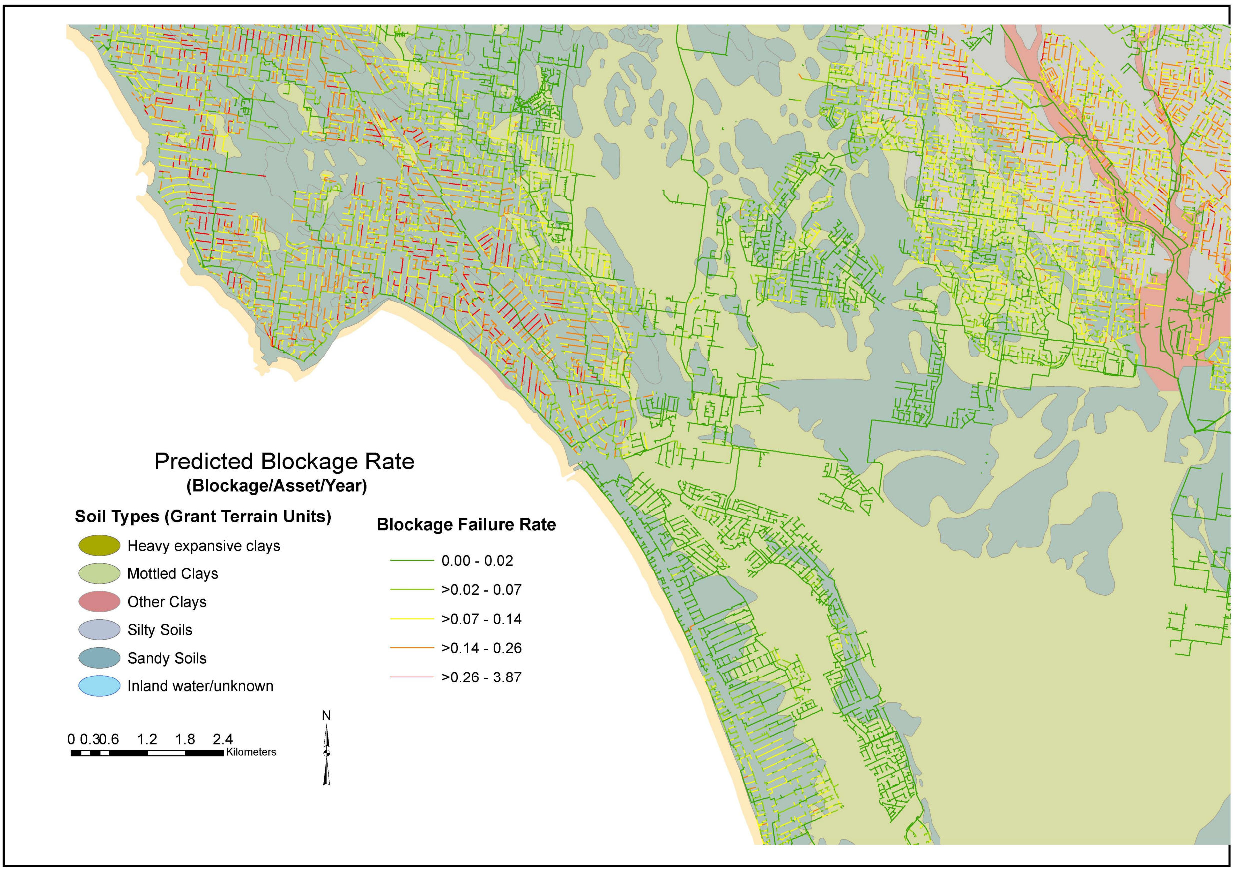
Root growth: Soil impedance to root growth (0 = very high → 9 = very low)

These environmental parameters are only part of the picture when trying to determine those sewers most likely to become blocked, as the structural condition of the pipe is a major determinant of the vulnerability to root blockage. Therefore, the analysis should also incorporate pipe characteristics such as age, diameter and material type in trying to identify assets at risk. A leaking sewer provides optimum growing conditions for tree roots, with good availability of water and nutrients, which encourages rapid root growth in the vicinity of the leak, as the tree exploits these conditions. If a root tip grows into an area of superior nutrient and/or water content then growth of the root system will be stimulated (Gilman, 1990). This response explains in part why a sewer that has joint cracks or other structural defects and is adjacent to trees is highly vulnerable to root intrusion that may lead to pipe blockage and loss of sewer function.

Figure 3 provides a depiction of an output from the modelling work displayed with GIS map layout. This figure shows no clear relationship between soils with low impedance for root growth and increased rate of recorded blockages. As although areas of sandy soils do present with high sewer blockage rates there are areas of sandy soils that exhibit low blockage rates. Physical parameters of the sewers, such as age and material type, have been shown in the statistical analysis to influence blockage rate. Relatively high blockage rates were identified for pipes of vitreous clay material and also there is a strong correlation between decreasing pipe diameter and increasing blockage rates.

Presentation in GIS format provides for clear dissemination of outputs that highlights spatial clusters of blockages and associated environmental characteristics, such as soil type. Map presentation of these outputs provides a powerful tool for communicating relationships in an intuitive fashion that can be readily understood. Langendorf (2001) proposes that the understanding of complex information and relationship is greatly enhanced if visualised.

Figure 3: Map of Soil Type and Predicted Sewer Blockage Rate



Further Work

A limitation of the study was the reliance on tree data that had been collected by local government. This data did not contain a complete record of urban trees that could potentially interfere with sewers, such as those on private land. For future projects it would be recommended that tree data is obtained for the entire sewer network using remote satellite imagery. Data capture through satellite imagery offers the advantages of enabling the mapping of a large geographic area quickly and also data can be updated on a regular basis to detect changes in urban vegetation. High resolution satellite imagery, such as from the QuickBird satellite, can be used to identify and classify urban vegetation. Vegetated urban areas can be separated from non-vegetated areas by the use of vegetation indices such as the normalized difference vegetation index (NDVI). This index is the normalised ratio of near-infrared and red reflectance that has been demonstrated to accurately describe vegetation due to its strong relationship with physical properties of vegetation (Ricotta *et al*, 1999). Ouma and Tateishi (2008) detail a study that used QuickBird Satellite imagery and NDVI classification to identify urban trees. The method developed was able to separate vegetation from non-vegetated urban areas, and also could delineate broad vegetation classes such as grass and trees.

Another consideration for further work is the inclusion of water table depth in identifying sewers at risk for blockage by tree roots. Tree roots, in general, cannot survive if submerged so sewers located below a permanent water table are not impacted by root intrusion (Duke and Jessen, 1996).

The risk cost of a sewer failure is a product of probability of failure and consequence of failure (Harlow, 2005). The first phase of this research has focussed on understanding the probability of sewer blockages while the next stage will look at determining the relative consequence of sewer failure across a network. Across a sewer network some assets are relatively more important than others in terms of consequence of failure. The relative consequence of failure can be influenced by minimum service level requirements, cost of repair, environmental sensitivity, social disruption, business impact and property damage. Assets which have a positive benefit-cost relationship for failure prevention should be managed proactively. A framework to assess consequence can be used in a process to prioritise asset inspection and renewal. Spatial representation of consequence of failure can help in identifying relationships with features that contribute to consequence of sewer failure, and also highlight clusters where there is a concentration of assets with high consequence of failure.

The identification of sewer assets that have both high probability of failure and a high consequence of failure will determine those assets that need to be managed proactively through regular maintenance and inspection, and possible renewal.

Conclusions

This project has demonstrated the role of GIS analysis in understanding the interaction between sewer blockages and environmental parameters that are spatially heterogeneous. The currently limited understanding of sewer root blockages and their causes means that effective management and maintenance strategies are difficult to develop and implement. Identifying those sewers at a relatively greater risk of root blockages will enable targeted CCTV inspection for early identification and repair of any problems. Identifying through GIS analysis spatial clusters of pipes that have a greater risk of root blockage can improve the cost effectiveness of CCTV inspection by focusing in areas of the network that have a relatively high risk.

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